FM-CW Based Miniature SAR Systems for Small UAVs

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ABSTRACT

In some earth observation applications there is a requirement for low cost, high performance imaging radar systems small enough to be operated from small, even unmanned, aircraft. The existing pulse radars are non-cost effective complex systems. Therefore they are not suited for these applications. Frequency Modulated Continuous Wave (FM-CW) radar systems are on the other hand generally very compact and relatively cheap to purchase and to use. IRCTR, together with TNO, is investigating the feasibility of combining FM-CW technology and high resolution Synthetic Aperture Radar (SAR) techniques. This research has led to the development of two different systems.

An FM-CW millimetre wave SAR sensor (35 GHz) was built and is being tested. The system is battery powered and uses a PC to control the radar and store the data, including GPS and data from motion sensors. The system is mounted in a pod attached to a light motor glider. Furthermore, a detailed system model has been developed in order to estimate and analyze the performance of the demonstrator system. The measurements made with the demonstrator system are evaluated and the findings are used to improve the system model. This improved model will be a strong aid in the design of future higher performance FM-CW SAR systems.

The second development regards a miniature P-band (450 MHz) polarimetric FM-CW SAR. This system is intended for use with an ultra-light aircraft. It is designed for tropical forest monitoring studies but could be used in foliage penetration applications as well. This system will be battery powered and uses a small memory stick to store the raw data. Data processing is now foreseen as an off-line activity. The design of the system is still under study and the realization is expected to start in the second half of 2005. This system will employ a Direct Digital Synthesizer to generate the waveform that is transmitted at P-band. Two separate dual polarized patch antennas will be used for transmit and receive.

1.0 INTRODUCTION

Some airborne earth observation applications require low cost, small imaging radar systems of high performance. Such systems should be suited for operation from very small, possibly even unmanned, aircraft. Coherent pulse radars are usually complex systems being neither compact nor cost effective. FM-CW radar systems are on the other hand generally very compact and relatively cheap to purchase and to use. IRCTR investigates together with TNO the feasibility of FM-CW SAR in the field of airborne earth observation. The combination of FM-CW technology and high resolution SAR techniques has led to the development of several small, cost effective SAR systems that can be used on small platforms. SAR is a novel application for FM-CW radar systems. Two developments are ongoing:

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An FM-CW millimetre wave SAR sensor (35 GHz) was built and is being tested. Within the frame of the project a fully operational airborne demonstrator has been developed. This system is mounted in a pod, is battery powered and uses a PC to control the radar and store the data, including GPS and data from motion sensors. The radar unit was originally designed for collision avoidance radars and is very small and of light weight, less than 1 kg. The range is limited to less than 1 km, which is sufficient for the demonstration of the concept. A Stemme light motor glider is available as a low cost test platform. Furthermore, a detailed system model has been developed in order to estimate and analyze the performance of the demonstrator system. The measurements made with the demonstrator system proved the validity of the FM-CW SAR algorithms although the poor performance of the sensor due to the non-linearity of the sweep and the high noise level prevented obtaining a good SAR image.

Based on the experience and know-how obtained with the FM-CW millimetre wave SAR sensor a second development is currently ongoing in IRCTR. The second development regards a miniature P-band polarimetric FM-CW SAR. This system is intended for use with an ultra-light aircraft. It is designed for tropical forest monitoring studies carried out by the Wageningen University (WUR) in sites managed by the Borneo Orangutan Survival Foundation (BOS) in Indonesia but could be used in foliage penetration applications as well. This system will be battery powered and uses a small memory stick like data recording device to store the raw data. Data processing is now foreseen as an off-line activity. The design of the system is still under study and the realization is expected to start in the second half of 2005. This system will employ a Direct Digital Synthesizer to generate the waveform that is transmitted at P-band. Two separate dual polarized patch antennas will be used for transmit and receive. In the paper the design will be discussed in detail.

Section 2 of this paper exposes the principles of FM-CW radars. Section 3 gives an overview of the SAR principles and discusses the differences between pulse and FM-CW SAR signal processing. In section 4 the platforms used in both High resolution FM-CW SAR and P-SAR projects are described. Section 5 describes the high resolution FM-CW SAR project. A description of the system is provided and the results of some airborne tests done so far are commented. Section 6 describes the P-SAR project. Section 6.1 includes an overview of several applications that P-band systems have and the requirements for the actual application of the system; tropical forest monitoring. In section 6.2 the system is described while in section 6.3 the time schedule of the complete P-SAR project is commented.

2.0 FM-CW RADAR PRINCIPLE

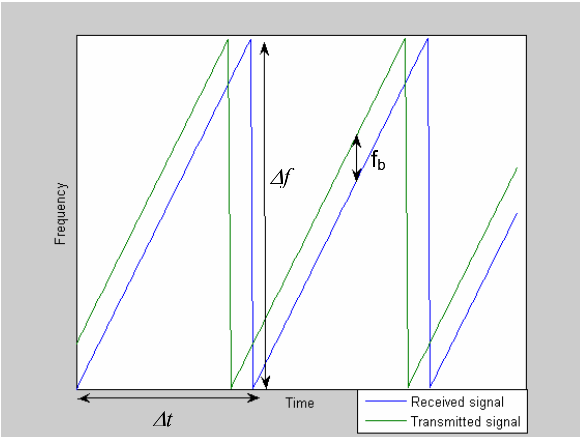
In FM-CW radar the transmitted frequency is a function of time, widely used modulation schemes are sawtooth and triangular modulations. Assuming the transmitted frequency to be sawtooth modulated, as shown in Figure 1a, the ideal transmitted signal can be written as:

$$s_T\left(t,t_n\right)=e^{j2\pi\left[f_o\left(t-t_n\right)+\frac{\alpha}{2}\left(t-t_n\right)^2\right]}rect\left[\frac{t-\Delta t/2-t_n}{\Delta t}\right] \tag{1}$$

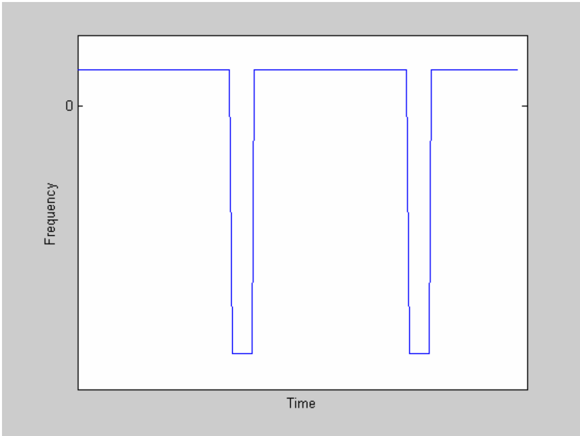
where f_o is the carrier frequency $\alpha=\Delta f/\Delta t$ is the chirp rate. Δt is the sweep repetition interval and Δf is the frequency sweep. $t_n=n\Delta t$ is the slow time variable, as opposed to the fast time variable t. Amplitude values are neglected. The received signal from a point scatterer is the transmitted signal delayed in time by the round trip propagation time to the scatterer and back, $\tau=2R/c$, where c is the speed of light and R is the distance between the radar and the scatterer. After mixing, the intermediate signal is obtained:

$$s_{IF}(t) = e^{j2\pi\left[f_o\tau - \frac{\alpha}{2}\tau^2 + \alpha\tau(t-t_n)\right]} rect\left[\frac{t - \Delta t/2 - t_n}{\Delta t}\right] \tag{2}$$

As can be seen in (2) the resultant beat frequency $f_b = \alpha\tau$ is proportional to range. It is assumed here that the target is stationary. If the target is moving, an additional Doppler frequency shift f_d is superimposed on the beat frequency.



(a)



(b)

Figure 1: (a) The Instantaneous Frequency of the Transmitted and Received Sawtooth Modulated Signals. (b) The Resultant Beat Frequency after Mixing the Transmitted and Received Signals.

Fig. 1b shows the beat frequency corresponding to the transmitted and received signals of Fig. 1a. From the figure it can be seen that the beat frequency is positive on one part of the modulation cycle and negative on the other part. It is common practice to use only the positive beat frequencies to obtain the range information. Note that the range resolution will deteriorate if only part of the sweep is used to determine the range. However, generally the part of the sweep with negative beat frequencies is very small.

A well-known problem in FM-CW radars is the leakage signal arriving at the receiver via the direct coupling between the transmitting and receiving antennas. The noise side bands of the leakage signal, the phase noise, could mask echo signals, if the antenna isolation is insufficient, or the phase noise of the local oscillator is too high. The slope of the phase noise can be approximated by $1/f$ [1], where f is the offset frequency from the carrier. In FM-CW radars this offset frequency is proportional to range therefore the phase noise is proportional to $1/R$. The received signal, on the other hand, is proportional to $1/R^3$ [2]. Therefore, the phase noise from a strong echo at short range can mask long range weak scattering.

3.0 FM-CW SAR PRINCIPLE

Opposite to pulse radars, where the raw signals are given in the time domain, the beat frequency is the starting point of the following processing algorithms and therefore signals are given in the frequency domain. The SAR signal processing starts from the mixed signal given by equation (2). In pulse radars a short pulse is transmitted. Therefore the movement of the aircraft within the transmission of the pulse is negligible. In this case the stop-and-go approximation, i.e. the assumption that the platform stops, the radar transmits and receives a pulse, and the platform moves to the next position can be applied. Since in general in FM-CW radars the duration of the sweep is much larger this assumption is not valid anymore, especially for high speed platforms.

Assuming that the antenna is pointing perpendicular to the flight path, the distance between the antenna and a scatterer placed at an azimuth position *x* and range position *r* is a function of time and is given by:

$$R(t,t_n) = \sqrt{r^2 + \left(v(t_n + t) - x\right)^2} \tag{3}$$

where *v* is the velocity of the platform. Considering, for simplicity, that *x*=0 and assuming that the range position is much further than the azimuth position, τ, the round trip delay between the sensor and the scatterer, can be written as:

$$\tau \approx \frac{2r}{c} + \frac{v^2 (t_n + t)^2}{rc} \tag{4}$$

In order to gives and insight on the phase terms conforming the received signal (4) is substituted in (2). The term τ^2 is usually negligible or can be corrected by residual video phase remove [3]. If it is suppressed in (2), the following expression is obtained:

$$e^{j2\pi\left[\frac{2r}{c}f_o + \frac{2r}{c}\alpha t + \frac{f_o v^2}{rc}t^2 + \frac{\alpha v^2}{rc}t^3 + \left(2\frac{f_o v^2}{rc}t + 2\frac{\alpha v^2}{rc}t^2\right)t_n + \left(\frac{f_o v^2}{rc} + \frac{\alpha v^2}{rc}t\right)t_n^2\right]} \tag{5}$$

The objective of the SAR processing is to compress the scatterer response in both azimuth and range directions. To do so a two-dimensional Fourier analysis with phase correction must be carried out. The information about range position is carried by the phase term $2r\alpha t/c$, while the time variation of the Doppler frequency given by $f_o v^2 t_n^2 / rc$ provides the azimuth position. Note that the fact that the stop-and-go approximation is not valid for FM-CW SAR systems introduces more phase terms that have to be corrected.

After the SAR processing the azimuth resolution is given by [3]:

$$\Delta x = \frac{v}{2 f_{D_{\max}}} \tag{6}$$

where f_{Dmax} is the maximum Doppler frequency of the scatterer. The maximum Doppler frequency is given by:

$$f_{D_{\max}} = -\frac{2v\sin\left(\theta_{az}/2\right)}{\lambda} \tag{7}$$

where θ_{az} is the angular azimuth beamwidth and is the wavelength. If (7) is substituted in (6) it follows:

$$\Delta x = \frac{\lambda}{2 \cdot 2\sin\left(\theta_{AZ}/2\right)} \approx \frac{\lambda}{2\theta_{AZ}} \tag{8}$$

This result leads to two interesting conclusions about synthetic aperture radars. The first one is that the resolution is inversely proportional to the azimuth beamwidth. A wider beamwidth (and therefore a smaller antenna) allows a better azimuth resolution. The second one is that the resolution is not anymore dependant on the range. That is the reason why synthetic aperture techniques are increasingly popular in imaging radar applications.

In this analysis differences between pulse and FM-CW SAR processing for the ideal case where the platform is moving at a steady velocity and the antenna is pointing perpendicular to the flight path has been considered. However, undesired movements of the platform that can lead to a change in the trajectory or the appearance of a squint angle in the pointing of the antenna have also to be corrected. In [4] more details on the signal processing algorithms can be found.

4.0 AIRBORNE PLATFORMS USED IN THE PROJECT

Two different platforms are being used in the on-going projects. For the 35 GHz High resolution FM-CW SAR system the Stemme S10 motor glider is being used. The 450 MHz P-SAR project will be mounted in an Edge X ultralight aircraft. This section provides some details on the aircrafts.

(a)

(b)

Figure 2: The Platforms used: (a) The Steme S10 Motor Glider and (b) The Edge X Ultralight Aircraft.

4.1 The Stemme S10 Glider

The Stemme S10 is a twin seat, light surveillance motor glider that can take off unassisted. It has a stalling speed (minimum velocity to maintain flight level) of 78 km/h. When powered it has a maximum cruising speed of 248 km/h. It can fly at altitudes up to 9140 m. It has 2 fuel tanks of 45 l each, which allows a range of about 1290 km. The glider also offers the possibility of flying unpowered, which minimizes the vibrations of the aircraft. In this case the best glide ratio (distance travelled divided by the decrease in altitude) is 50 and it is achieved at 106 km/h.

Two standardized pods can be mounted under the wings. These pods have a diameter of about 35 cm and they are 80 cm long excluding the aerodynamic fairings. The maximum payload is 50 kg per pod.

4.2 The Edge X Ultralight Aircraft

The Edge X is a two-seat microlight aircraft from Airborne Australia. It is equipped with Streak Wings. The main advantages of this kind of aircraft are their portability, ease of set-up and maintenance and mechanical simplicity. They can land and take-off without requiring a conventional airstrip or specialized fuel. The manufacturer claims that it is very stable even in adverse conditions and that the roll and pitch is very light and predictable but this aspect has to be analyzed.

The dimensions from wheel to wheel are 1.89 meters. The aircraft total empty weight is a minimum of 167 kg and the maximum take off weight is 401 kg. If we assume that it can carry two persons, on average 160 kg, this leaves 74 kg as a total payload. However, considering that it may also carry other equipment and that with lower weight it has better manoeuvrability, it is advisable not to exceed a 50 Kg payload.

The trim speed (the band of velocities where the glider flies without manoeuvring) is between 74 and 92 Km/h (20.5 to 25.5 m/s). The maximum level speed (maximum speed at a certain level) is 138 km/h at minimum weight and 148 km/h at maximum weight. It can fly at altitudes varying from 300 to 1000 m. It has a 44 l fuel tank, which leads to a range of about 300 km or 3 hours duration, depending on weather conditions and loading.

5.0 35 GHZ SAR DEVELOPMENT

5.1 System Design

The work on the demonstrator system started in 2001. In order to speed up the development and to show that an FMCW SAR system can be relatively cheap, it was decided to use off-the-shelf components as much as possible.

The demonstrator system operates in stripmap mode. The resolution in range as well as in azimuth direction has primarily been chosen to be 1 m. During the project, the resolution will be gradually enhanced to 30 cm in both range and azimuth direction. Further specifications are listed in table I.

Table I: 35 GHz FM-CW SAR System Parameters (High Resolution Mode)

Carrier frequency	35 GHz	Antenna Gain	24 dB
Frequency sweep	500 MHz	Antenna Isolation	52 dB
PRF	1 kHz	Beamwidth Az/El	6°/28°
Modulation	Sawtooth	Platform velocity	25 m/s
IF band	Dc to 2.5 MHz	Altitude	150 m
Transmitted power	18 dBm	Max. Range	730 m

The core of the demonstrator system is a PXI chassis manufactured by National Instruments. The chassis includes a 1.26 GHz Pentium III controller, a 10 MHz, 12-bit A/D board to sample the radar data, a 100 kHz, 16-bit A/D board to sample the motion data, and a 40 MHz, 12-bit D/A board to control the frequency modulation. The radar data are sampled at 5 MHz; resulting in a continuous data rate of approximately 9.5 Mbyte/s. The 35 GHz FM-CW front-end is manufactured by Epsilon-Lambda Electronics. In addition, the demonstrator system is supplied with gyroscopes, accelerometers and a GPS receiver to be able to determine the position and the attitude of the system. Finally, a digital camera has been added to supply optical images of the imaged area.

During the flights, the demonstrator system can be controlled and monitored from the cockpit with the aid of a pocket PC. To this end, some cables can be pulled from the pod to the cockpit through a tube in the wing. Otherwise, the system is self supporting; it is fed by a battery which is also installed in the under wing pod. The system can run for approximately 2.5 hours on a fully charged battery.

Figure 3: FM-CW Radar Mounted in the Pod Attached to the Plane Wing.

5.2 Measurement Results

An airborne campaign was organized at the Strausberg airfield, Germany, on June 22nd and 23rd, 2004. Four corner reflectors were placed in a grass field, see Fig. 4a, and the GPS coordinates of their positions were measured. Two small 33 RCS dBm^2 corner reflectors (1 and 2) and two large 40 RCS dBm^2 corner reflectors (3 and 4) were set up. Moreover, a GPS ground station was set up in the middle of the scene. Several runs were flown along the corner reflectors at 100, 150, and 300 m altitude. Additionally, some flights were made at an altitude of 200 m, during which the engine of the motor glider was switched off. The weather was very turbulent and the wind was directed almost perpendicular to the runway. A squint angle due to the aircraft yaw was therefore present during most measurements. The data presented in the paper are obtained from a run flown at 100 m altitude.

The slant range to the middle of the scene is around 240 m. In this case, the demonstrator system was operating in low resolution mode transmitting a bandwidth of 200 MHz, leading to a theoretical range resolution of 75 cm. The azimuth compressed data are shown in Fig. 4b. Multilook with a reduction factor equal to 16 has been used to reduce the speckle and so enhance the contrast of the image; of course also the azimuth resolution has increased with the same factor. The geometry of the responses corresponds very well to the geometry shown in Fig.4a. The practical range resolution is about 2 m, which is almost three times the theoretical resolution. The spreading is mostly due to the residual frequency sweep non-linearity. This residual non-linearity may be further compensated with auxiliary data processing. The resolution in azimuth direction is around 50 cm (in the multilook image), which is already very good.

Table II: Calibration Results Obtained by Processing the Images Collected during the Airborne Campaign

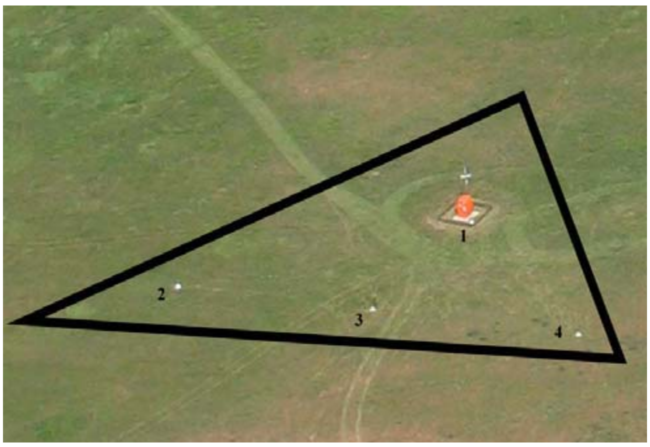
Corner 1 RCS	32.3 dBm^2
Corner 2 RCS	33.2 dBm^2
Corner 3 RCS	37.8 dBm^2
Corner 4 RCS	40.0 dBm^2
Image clutter σ_o	19.9 dB
Noise σ_o	17.9 dB

The peak level of the response of the 40 dBm^2 corner reflectors is about 18 dB above the noise level. In order to investigate the performance a calibration process was carried out from the data collected. From the measured image response of the known reference the backscatter coefficient for uniform areas in the image can be derived, and by using an integral calibration approach the method is independent of the azimuth or range resolution and it does not involve the scene, radar, or processor partial coherence [5]. The use of multilook images does not influence the integral calibration algorithm.

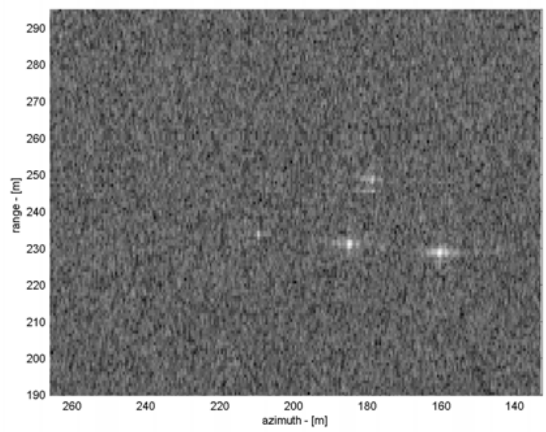
Corner reflector 4 (see again Fig. 4a) has been chosen as the known reference reflector and its RCS has been set to a value of 40 dBm^2, its theoretical value. The backscatter coefficient of the clutter and of the other corner reflectors has been calculated from this reference reflector. The same procedure has been repeated using also other images of the same area in order to collect a valid data set and then averaging the results in a root mean square way. For the calculation of the noise level, a file has been collected with the radar pointing at the sky. Raw data have been processed with the SAR processor, so that this noise data have passed through the same processing chain as the aircraft data. Results are shown in table II. From these two conclusions can be drawn:

- the RCSs of the corner reflectors are quite consistent with the theoretical values: 33 dBm^2 for corner 1 and 2, and 40 dBm^2 for corner 3 and 4;
- the backscatter coefficient of the clutter is close to the equivalent backscatter coefficient of only noise.

The value of the backscatter coefficient for grass is around -12 dB [6], so between the expected one and the calculated one there is a difference of more than 30 dB. Some of this discrepancy can be explained by the fact that the corner reflectors could not be exactly pointing at the radar, but still the difference between the theoretical and the calculated backscatter coefficient is quite high. What has been measured as clutter is therefore only noise. When the noise data have been collected the set up of the radar was a little bit different than during the airborne measurement: the pod cover was not used, and the power supply for the motion sensors was disassembled. It has been seen in other tests that both of them have some influence, specially the power supply. This could explain the difference of 2 dB between the noise level in aircraft images and the level in the noise file. The results from the airborne campaign are promising even if the noise level [7], is the major limitation. However the corner reflector responses are enough to validate the signal processing. In [8] to [10] details on other tests made can be seen.



(a)



(b)

Figure 4: (a) Airborne Picture of the Area of Measurements with the Corner Reflectors (numbered 1 to 4) and (b) SAR Image of the Four Reflectors after the Squint Angle Correction.

6.0 450 MHZ P-BAND POLARIMETRIC SAR DEVELOPMENT

6.1 Application and Requirements

P-band offers unique capabilities that have not been fully exploited yet. Its large wavelength allows penetrating surfaces like forest canopy, ice sheets and certain kinds of soil. Thus, very useful data, that could not be obtained otherwise, can be retrieved. Indeed this frequency range has revealed such a potential that there are on-going discussions in the International Telecommunications Union (ITU) on the convenience of allocating a specific band for earth observation systems in the 420-470 MHz range and therefore diminish the problems of interference that the existing systems currently face. Applications from space are enabled this way.

The capability of penetrating the sub-surface of P-band has revealed this frequency to be the most adequate in a wide range of applications. As an example there have been studies on the application in the determination of soil moisture and dielectric properties. Other studies suggest the suitability of P-band to detect man-made structures like archaeological sites, and recent experiments have proved it adequate to detect water in dry areas. P-band also has applications to ice sheet studies. Data from P-band imaging radars can help estimating the internal structure of ice sheets and therefore provide a vision of the evolution of the ice sheet in the poles which could help determine the impact of climate change. The ability to penetrate dense forest canopy makes P-band adequate for topographical studies in these areas.

Another important commercial application is its use in sea bottom topography. Under favourable meteorological conditions the bottom topography of seas can be mapped with airborne radars. The interaction between marine currents and the bottom topography causes variations in the surface current velocity. These variations give rise to differences in the spectrum of the wind-generated waves, which can be observed by the radar. Sea bottom topography using airborne radar avoids or reduces the use of expensive bathymetric mapping from ships.

The P-SAR system designed will be used in tropical forest monitoring activities in Indonesia. Within the ESA Earth Explorer Opportunity Mission (EEOM), the programme BIOMASCA has been proposed for worldwide forest biomass monitoring using polarimetric P-band SAR. Plans are going on to study the practicability of a satellite based P-band SAR. However, the poor availability of P-band data has prevented development of robust biomass estimation algorithms. Especially the lack of data in the tropics (where biomass levels can be much higher), and the general lack of multi-temporal data are considered as a major problem. The variety of existing biomass levels over the test sites in Indonesia (of the BOS organisation) will give insight into the possibilities and limitations of long wavelength SAR for direct biomass estimation. BOS and WUR intend to acquire observations over long time periods to capture seasonal variations. Thus, a unique and very meaningful scientific data set will be collected.

Moreover, most of the world’s tropical peat swamp forests are located in Indonesia (30 out of 50 million ha). These areas are relatively small but contain enormous carbon stocks, approximately equal to the carbon stored in all temperate forests of the world together. Because of deforestation and land use change these areas are at risk and are already producing enormous carbon emissions (through oxidation and fire). These emissions are a major threat to the world’s climate. Peat land restoration is considered urgent and very important. A key element of peat land restoration is the ability to get information on hydrology and flooding under the forest canopy. P-band radar is the best suitable instrument for this purpose. The use of P-band in peat swamp forests will be studied by WUR and BOS and a link will be made to temporal dynamics of flooding. For this purpose one of the peat swamp areas under management by BOS is equipped with permanent hydrological sensors measuring water levels along a large 23 km transect across a peat dome.

The radar should be fully polarimetric for better land use classification capabilities. Since the area under observation is quite homogeneous and the measurements are meant for investigation of future satellite missions, a high resolution will not be necessary. A maximum of 30 meters in ground range resolution is considered sufficient, but 15 meters is desired. Multiple looks will be used in order to reduce speckle noise.

Considering the increasing interest in developing a spaceborne P-band SAR, small angles of incidence are preferred. The six major types of forest to be observed are palm oil, rubber, mangrove, secondary tropical forest, primary tropical forest and primary tropical forest burnt. The reflectivity of these areas varies from -5 dBm^2 to -35 dBm^2. The dynamic range between the cross-polarized and co-polarized channels is 15 dB. The desired clutter-to-noise ratio (CNR) after the signal processing is a minimum of 15 dB. Table III summarizes the requirements of the system.

Table III: Specifications of the System

Ground range resolution	<15 m (<30 m max)
Azimuth resolution	<1 m (<15 m multilook)
Number of looks	>15
Swath width	800 m
Angle of incidence	25^o to 65^o
CNR^{SAR}	>15 dB
Altitude of the platform	500 to 600 m
Velocity of the platform	75 km/hr

6.2 System Design

The core of the system is the DDS. This device synthesizes the chirp signal. Different modulations can be performed by simply programming several registers. The device can synthesize signals with a bandwidth up to 100 MHz, which gives a great flexibility when performing the modulation. A clock signal at a rate equal to the sweep repetition frequency (SRF), *I/Oclock*, is available for external use. The DDS is controlled by a microcontroller.

The output signal of the DDS is then upconverted to the carrier frequency by using a 400 MHz low phase noise crystal oscillator and an active mixer. After being filtered, the resultant signal is amplified and sent to the antenna. A switch controlled by means of the I/O clock drives the signal sequentially to the vertical or the horizontal polarization feeding points of the antenna.

An antenna similar to the one used in transmission receives the echo from the scatterer. The signals received from the horizontal and vertical polarization feeding points are processed separately. The received signal is first amplified by a low-noise amplifier. After amplification it is mixed with a portion of the transmitted signal in an active mixer. The resultant low frequency signal is filtered and amplified before being digitized and stored in a data acquisition system. The data acquisition system consists of an analog to digital converter and a set of flash memories controlled by a microcontroller to store the data. In order to increase simplicity the processing of the data is done off-line. The microcontroller has a USB interface to facilitate the transfer of the stored data to a PC.

The whole system timing is based on the 400 MHz oscillator used to upconvert the signal. The sinusoidal output of the oscillator feeds a comparator integrated in the DDS. The output of the comparator is divided by 2 in order to supply the internal clock signal for the DDS. This internal clock signal is also used to control the data acquisition system.

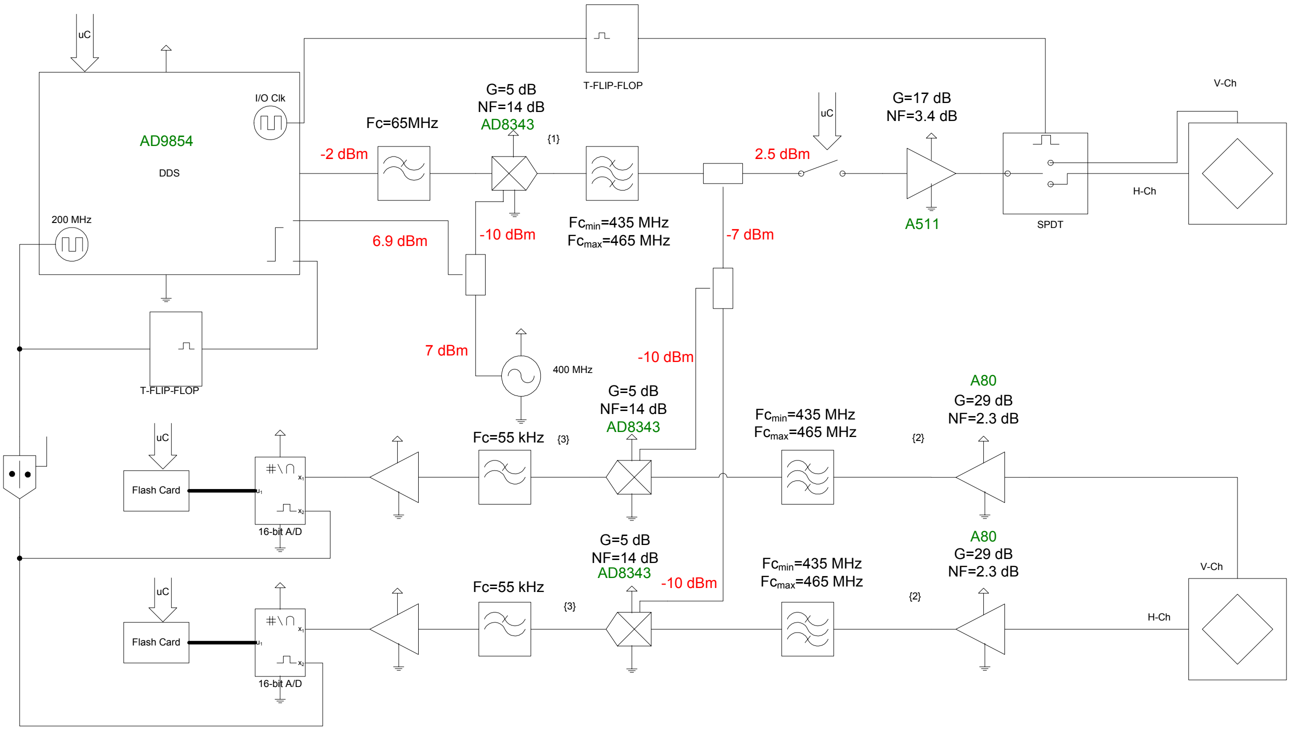


Figure 5: Block Diagram of the P-SAR System.

6.3 Development Plan

Preparatory work on this project has already been performed. During the pre-project stage literature research has been carried out, the required specifications of the system have been established, the main aspects and challenges have been taken into consideration and an initial design of the system has been made [11].

Based on this pre-project work a four-year research should be conducted in order to realize and test the system and to carry out FM-CW modulation studies. The system should be realized by the end of the first year. The second year will be devoted to ground tests and flying tests in the Netherlands and by the third year the system should be operational on site.

The adaptation of the SAR algorithms developed for the 35 GHz high resolution FM-CW SAR system will start during the first year and will be conducted in parallel to the construction of the system. The third year will be devoted to test measurements and validation of the processing algorithms.

And initial study of FM-CW modulations with DDS based on literature research and simulation will start during the second year. Once the system has been tested and the algorithms are validated, FM-CW modulations will be studied from data obtained with the system.

7.0 CONCLUSIONS

In IRCTR, and founded by the Netherlands Science Foundation, STW, an investigation is ongoing on the feasibility of FM-CW SAR systems mounted on small aircraft. The first system developed was a 35 GHz high resolution FM-CW SAR. The limited performance of the radar sensor, which was adapted from an existing automotive radar in order to speed up the investigation, has prevented obtaining a good quality image. Nevertheless the measurements have allowed the validation of the FM-CW SAR signal processing algorithms.

Based on the know-how obtained in the previous project currently a second system is being developed. The second system is a P-band polarimetric FM-CW SAR which will be mounted in an ultralight aircraft. The system will be used by WUR and BOS to carry out tropical forest monitoring in Indonesia but P-band has a wide range of applications. Since the phase noise and the non-linearity of the sweep revealed to be the major problems in obtaining a good-quality image a low phase noise oscillator and a DDS (which provides a very linear modulation) will be used. This second system is expected to be operational in 2 years. A funding proposal has been submitted to STW.

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